The northern Creag Meagaidh massif: geomorphology and glacier modelling.

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Introduction

The northern Creag Meagaidh massif, which includes the upper Burn of Agie and upper River Roy basin, has received little glacial geomorphological research compared to the adjacent valleys of Glens Roy, Gloy and Spean. It is generally accepted that Main Late Devensian ice flowed through the area from the SW, and that ice margins retreated back towards the west during ice-sheet decay (Key et al., 1997; Finlayson, 2006). This is demonstrated regionally in the form of erratic dispersal, ice-moulded bedrock, moraine patterns and marginal meltwater channels. However, the extent and configuration of locally nourished glaciers during the subsequent Loch Lomond Stadial is less well established and reconstructions have varied (Fig. 1). In an effort to map Loch Lomond readvance limits throughout a wider region, Sissons (1979) suggested that restricted ice growth occurred in the Creag Meagaidh area, with one c. 5-km-long glacier in Coire Ardair, and a few smaller corrie glaciers elsewhere (Fig 1A). Results from BGS field surveying, reported in Key et al. (1997), were also interpreted to indicate limited glacier build up in the Creag Meagaidh massif during the stadial (Fig 1B). In contrast, Finlayson (2004) reconstructed an icefield > 27 km^2 in area, and suggested confluence of glacier ice draining the northern side of the Creag Meagaidh massif and the southern side of the Monadhliath, in the vicinity of the 350 m Glen Roy overflow col (Fig 1C). Finlayson (2004) proposed that such a configuration could have occurred early in the stadial, with local glacier retreat occurring prior to damming of the 350 m lake in Glen Roy. Finlayson (2006) subsequently revised these limits, re-interpreting ice-marginal landforms around Loch Spey as being older (Fig 1D). He also speculated that non-erosive, cold-based ice existed on the plateau during the stadial.

This short section describes some of the landforms on the northern side of the Creag Meagaidh massif, which are important for evaluation of the varying glacier reconstructions. The section finishes with a brief comparison of existing reconstructions with results from recent high resolution numerical modelling studies (Golledge, Hubbard and Sugden, 2008).

Geomorphology

Geomorphological descriptions of the wider Creag Meagaidh area can be found in Key et al. (1997) and Finlayson (2004, 2006). A c. 20 km circular route is described here, with the purpose of highlighting some of the key glacial geomorphological landforms that occur on the relatively unfrequented northern side of the Creag Meagaidh massif. The route is not necessarily proposed as a day trip, but more as a guide to some of the excellent landform examples which can be seen. It follows the Burn of Agie up through higher ground to Poite Coire Ardair at 1053 m OD (429 888), then continues north towards Loch Spey, before returning alongside the River Roy (Fig. 2). In places paths are poorly defined or non-existent, and appropriate consideration should be given to the terrain before entering into some of the more remote areas.

Follow a trail up the western bank of the Burn of Agie initially passing subtle morainic mounds and ridges on either side of the river. An obvious suite of sharp-crested, lateral moraine ridges up to 200 m in length and associated meltwater channels (1) soon becomes apparent on the eastern side of the river (Fig. 3). Glacially-transported boulders occur frequently in this area, but are virtually absent outside the outermost, well-defined, lateral moraine. Continue up alongside the river over peaty ground passing through a chaotic assemblage of < c. 5-m-high hummocky morainic ridges and mounds (2), and by a large, conspicuous, incised, flat-topped feature (3). Good sections exist here, although no detailed sedimentological work has yet been conducted.

Taking a slight detour on the northern side of the river provides good views of suites of boulder-strewn, hummocky, recessional moraines extending from the col under Meall a Mheanbh-chruid into the valley below (4) (Fig. 4). The moraines clearly mark successive palaeo-ice margins which retreated up valley through the col towards a source above it. Interestingly, morainic landforms are rare on the up-valley side of the col, implying that glacier ice in the source area did not readily form moraines. Walk east up a gentle, grassy slope to Carn Dearg (410 894) noting at first subtle, then more obvious solifluction lobes on approach to the summit. From here, good views can be obtained down to the corrie occupied by Loch Roy, where a further suite of boulder-strewn, hummocky moraine ridges and elongated mounds extend from Loch Roy towards the NW (5). From Carn Dearg walk across grassy terrain with patches of frost shattered debris towards the *window* (427 886), where a trail is gained leading up to Poite Coire Ardair (428 888). Arcuate boulder spreads can be seen bounding Lochan Uaine (6) – possibly remnants of the very final wastage of glacier ice in the area. Impressive meltwater channels (7) trending almost parallel to slope contours, drain towards the corrie of Loch Roy (Fig. 5). Subtle solifluction lobes and patches of frost-shattered debris occur below these channels, but the slopes above are mantled by much thicker spreads of coarse, shattered, angular debris.

Poite Ciore Ardair offers spectacular views down into Coire Ardair. Thick talus cones and bouldery debris mantle the upper slopes immediately below the *window*. Of particular note is the sharply-defined downslope limit of well-developed talus on the south-eastern slopes of Coire Ardair (8). This limit has been used in glacier reconstructions to infer an upper ice margin of a former glacier which occupied Coire Ardair (Sissons, 1979; Finlayson 2004, 2006). From here, walk NE for about 1 km along a broad ridge blanketed with frost-shattered cobbles and boulders (9), and past infrequent, scattered granitic erratics deposited during an ice-sheet stage. Views down to the excellent hummocky recessional moraines in Coire Ardair are available from the ridge (10).

Descend NW towards the western shoulder of Meall Ptarmigan (425 904) passing a series of meltwater channels (11) which trend obliquely across slope towards a small col leading to Coire Bhanain. Well-developed patches and lobes of frost-shattered debris can be seen immediately above the channels (Fig. 6).

From the western shoulder of Meall Ptarmigan walk northward though peaty and heather-covered ground, taking in views of the chaotic, moundy, boulder-strewn terrain occupying the upper basin of the River Roy. Passing a sharp lateral moraine and associated meltwater channel (12), come to a suite of sharp, boulder-strewn moraine ridges (13) on the western side of Sron Nead. From here, one can look down over large, and locally more rounded, morainic mounds and ridges (14) which continue to Loch Spey and beyond. At this stage, one option is to walk NE past Loch Spey to meet the road just beyond Melgarve Ford (464 959). This route follows the very upper stages of the River Spey through a series of larger morainic mounds and impressive esker systems (15). Alternatively, walk NW to join the River Roy and follow it down to a rough track at White Falls (396 933).

Collectively, geomorphological features on the northern side of the Creag Meagaidh massif suggest a period when ice sourced over high ground, and in north and east facing corries, drained northward down the Burn of Agie and the upper River Roy basin. Based on morphostratigraphic criteria (e.g. occurrence of hummocky moraine, presence or absence of periglacial features), Finlayson (2004, 2006) suggested such a configuration existed during the Loch Lomond Stadial. In places down valley, margins of former glaciers are clearly defined (e.g. the obvious limit of sharp lateral moraines on the eastern side of the Burn of Agie, Fig. 3.), while elsewhere distinct former glacier limits are less clear (e.g. the upper River Roy basin). Determining the age of the landforms extending down to, and beyond, Loch Spey is crucially important in order to validate or reject existing glacier reconstructions, and also because of potential implications concerning periods of lake overflow from Glen Roy (e.g. Fig 1C)

Similarly, up valley the abrupt termination of frost-shattered debris suggests clear former glacier margins, for example, in Coire Ardair. However, elsewhere patches of subtly soliflucted ground occur below ice marginal meltwater channels, and moraine patterns retreat towards higher ground where little evidence exists for former glaciers. The broad flat form of some upper areas of the Creag Meagaidh massif could have been favourable for accumulation of plateau ice (c.f. Manley 1955), and it is possible that some unclear upper former glacier margins are due to the existence of cold-based ice.

Insights from numerical glacier modelling

A new high-resolution numerical glacier model (Golledge et al., 2008) for the Loch Lomond Stadial in Scotland provides insight into the issues highlighted above. The model used owes its origins to Hubbard (1997, 1999, 2006), and its recent implementation to the simulations of Golledge et al. (2008). The output described here derives from the latter, where it is forced by a GRIP-pattern temperature depression based on the 20-year resolution $d^{18}O$ record (Johnsen et al. 1992) which is scaled to Scottish palaeotemperatures using an empirical transfer function derived from modern isotopic values in Greenland (Clapperton 1997). Precipitation across the model domain is calculated using an elevation-related scheme employing present-day values derived from the UKCIP dataset, which presents 5 km-resolution distributions for a range of climate parameters derived from multiple regression analysis of meteorological data from 3500 stations in the UK (Perry and Hollis, 2005). Precipitation patterns are further modified using manually-iterated eastward and northward reductions intended to replicate enhanced aridity in the lee of the main ice cap, as suggested by palaeoglaciological reconstructions (Sissons and Sutherland 1976). These temperature and precipitation values together form the input data necessary for the Positive Degree Day scheme used by the model to calculate accumulation and ablation across the model domain (Laumann and Reeh 1993), which ultimately defines the net mass balance regime of the evolving ice masses. The model is thermomechanically coupled, so, for example, basal pressure-melting arising from thickening ice leads to Weertman-type sliding at the glacier bed (Weertman, 1964), and heat advected through the glacier system influences the rate of its flow. Internal deformation of ice (creep) thus depends on glacier geometry, temperature, and a rate factor (Glen, 1955; Paterson, 1994).

Sensitivity tests intended to explore the parameter space of realistic model scenarios identified a narrow range of values that produced plausible glacier configurations that closely matched empirical Loch Lomond Stadial limits (Golledge et al., 2008). These experiments showed that a maximum mean annual temperature depression of -10 °C, coupled with a present-day precipitation pattern in western Scotland and a considerably more arid climate further east and north of Rannoch Moor, leads to growth of an ice cap along the axis of the western Highlands. Outlet glaciers radially discharge the main accumulation centres and in some cases exhibit mass balance lags that lead to climatically decoupled glacier responses.

There are a number of interesting features of the modelled ice mass in the vicinity of Creag Meagaidh (Fig. 7). First, the model predicts accumulation of cold-based ice over high ground. Interestingly, a cover of cold-based ice is also predicted over the

Monadhliath mountains to the north. Second, the model predicts that glacier ice fed from the northern side of the Creag Meagaidh massif coalesces with ice draining to the south from the Monadhliath, in the vicinity of Loch Spey. Third, modelled glacier ice extends to the east beyond Loch Spey. In sum, the model is most consistent with the reconstruction of Finlayson (2004), but with a large input from plateau ice.

While, the model cannot presently account for loch bathymetry and the build up of ice-dammed lakes, it is interesting to note the extent of glacier growth that is predicted to the east of Glen Roy. Modelled accumulation centres naturally give rise to an enclosed basin in Glen Roy, where initial meltwaters would have accumulated. Thus, given sufficient depth, calving at the eastern end may have limited westward expansion of glaciers draining the Creag Meagaidh and Monadhliath ranges. The model lends credence to the possibility that the 350 m Roy - Spey overflow col was occupied by ice for a period during the Loch Lomond Stadial (Fig. 1C), presumably prior to damming of the 350 m lake in Glen Roy. It is interesting to note that only pollen stratigraphic sequences characteristic of the Loch Lomond Stadial / early Holocene transition have been retrieved from this area (Lowe and Cairns, 1991), although that could also reflect the scouring action of overspill waters. Nonetheless, modelling results coupled with geomorphological observations suggest that establishing an age of the landforms around Loch Spey is crucial to further understanding of the Lateglacial history of Glen Roy.

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Figures

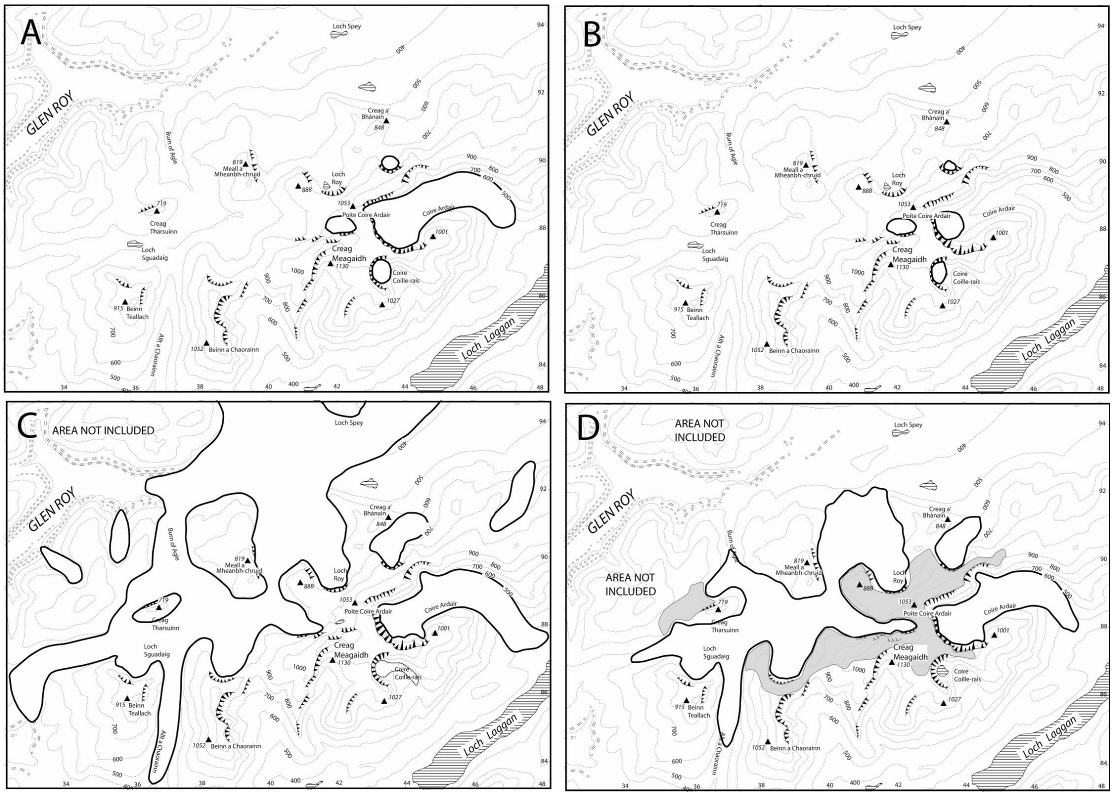

Fig. 1. Loch Lomond Stadial glacier reconstructions for the Creag Meagaidh massif: (A) Sissons (1979), (B) Key et al. (1997), (C) Finlayson (2004), (D) Finlayson (2006). Grey area indicates speculative cold-based ice.

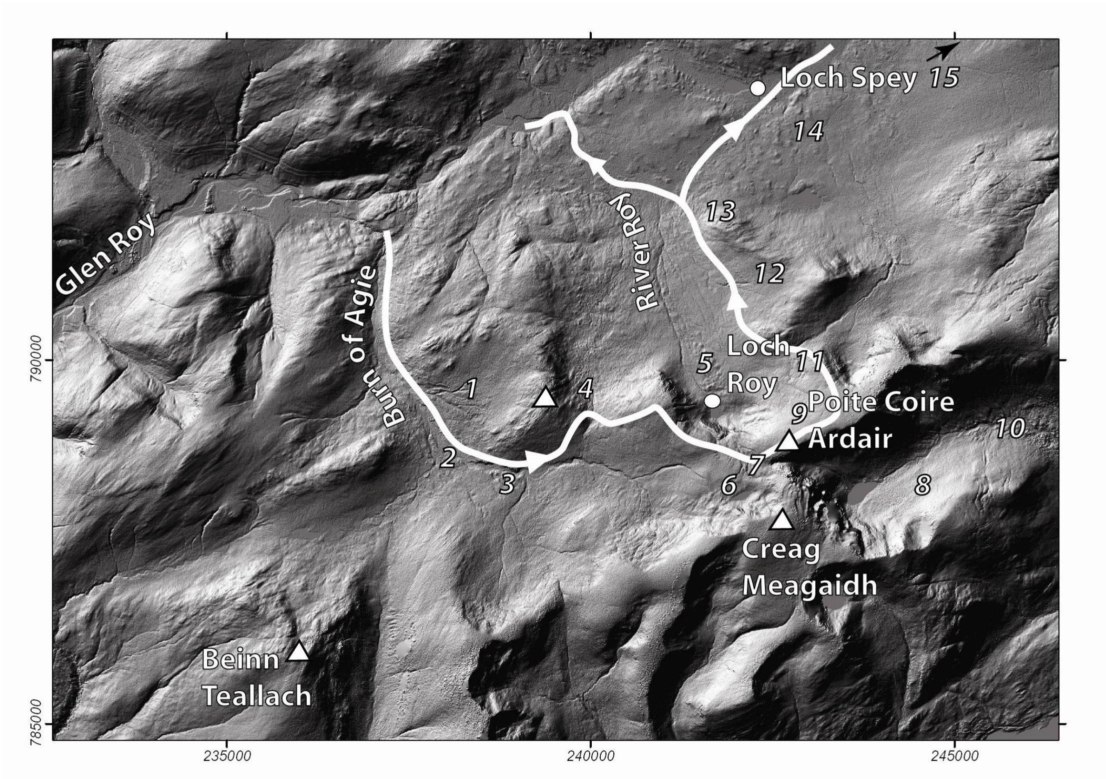

Fig. 2. NW hill-shaded digital surface model built from Intermap Technologies NEXTMap topographic data showing area described. Numbers indicate localities referred to in text.

Fig. 3. Lateral moraines and meltwater channels around the Burn of Agie.

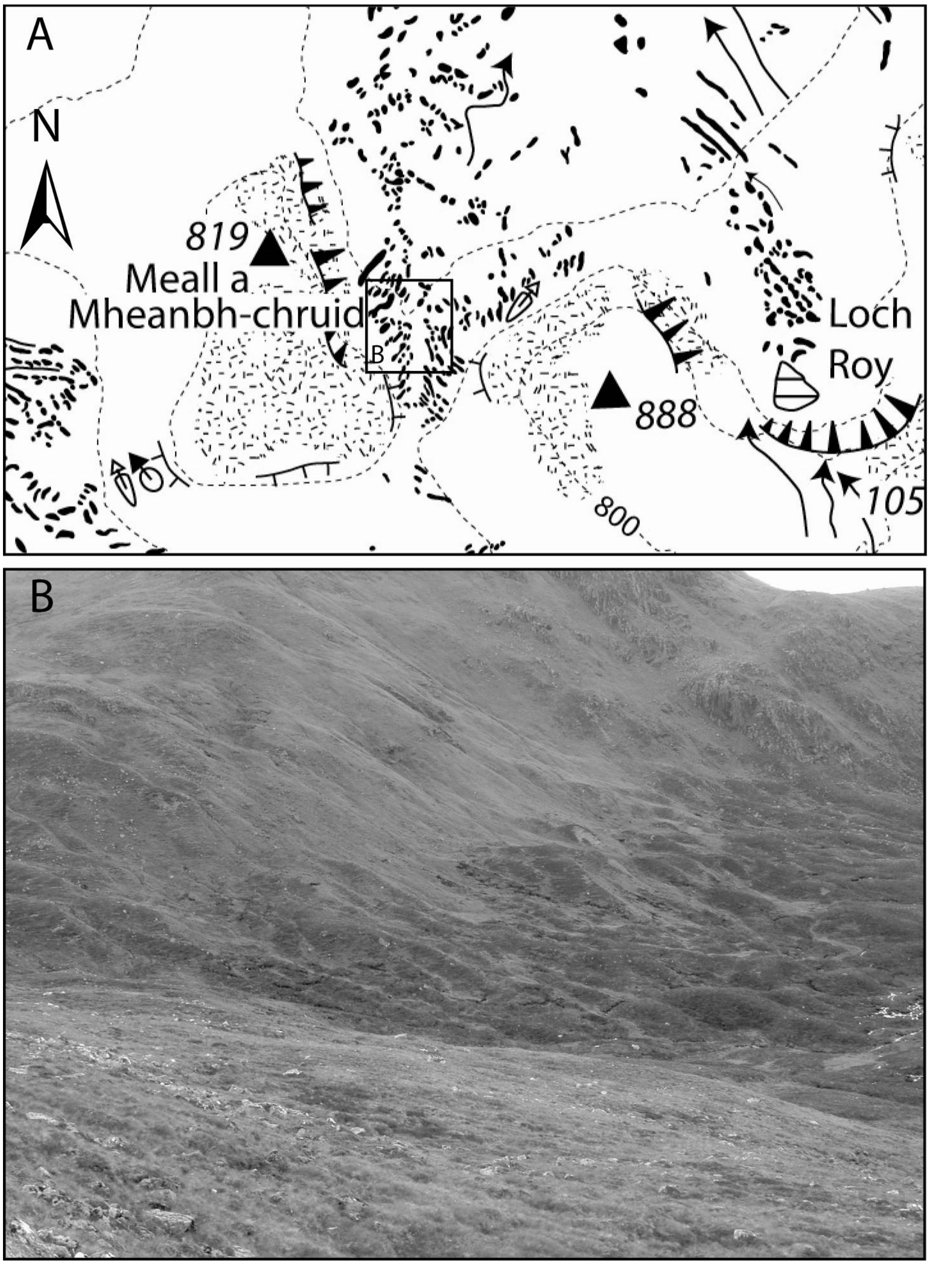

Fig. 4. Hummocky recessional moraines viewed from the col below Meall a Mheanbh-chruid.

Fig. 5. Meltwater channels draining towards Loch Roy.

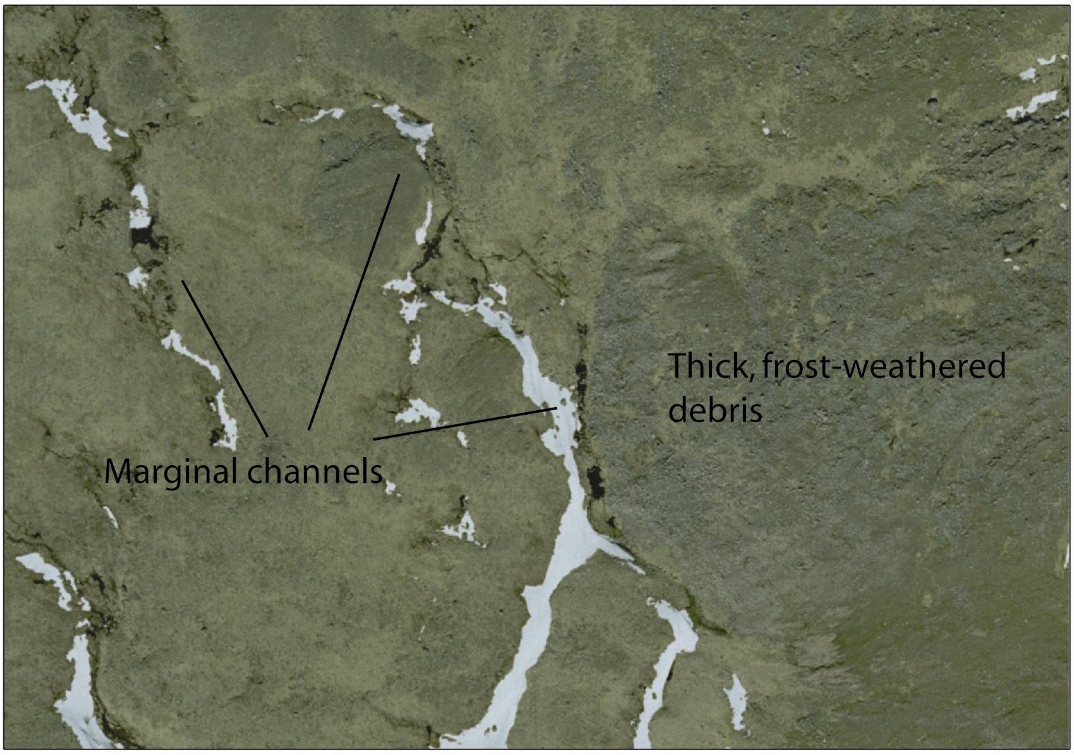

Fig. 6. Aerial photograph showing spatial relationship between frost-weathered debris and marginal meltwater channels.

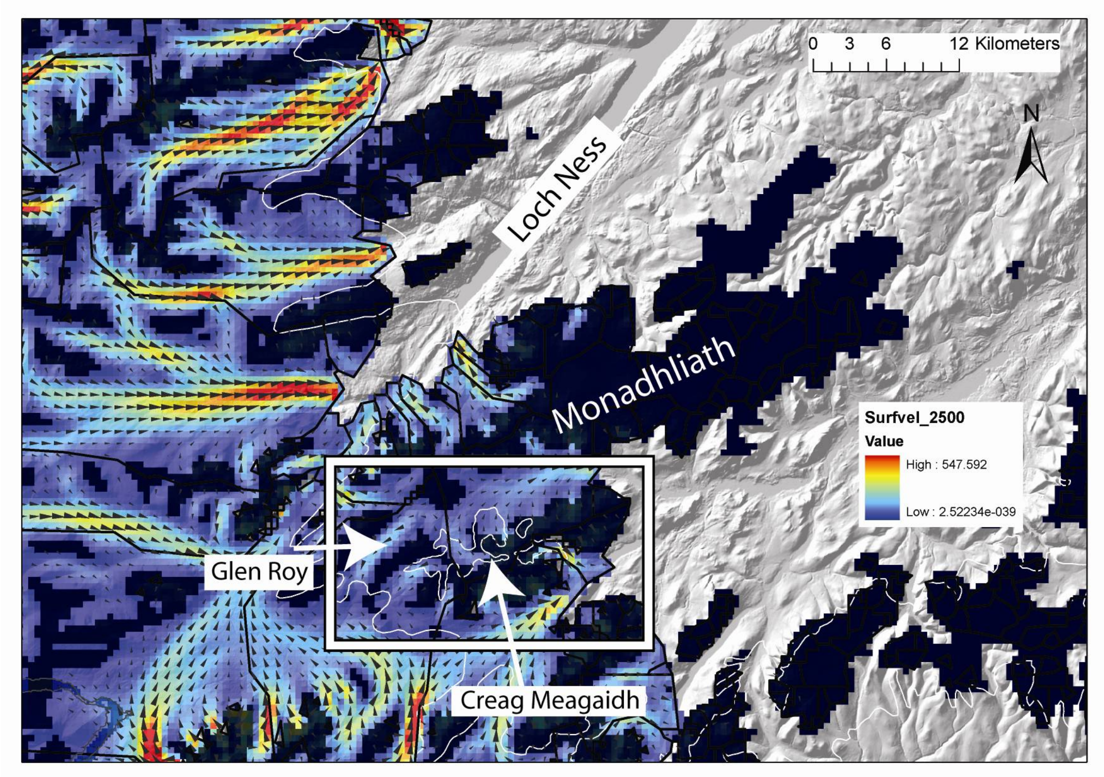

Fig. 7. Modelled ice extent in the vicinity of Glen Roy at 12,500 yrs BP. Dark areas indicate modelled thin, immobile ice, while lighter areas show glacier flow with basal sliding. Arrows: ice flow vectors.